MEAN LAKE LEVELS DURING JUNE, 1914.

The following data are as reported in the U.-S. Lake Survey "Notice to Mariners" dated Detroit, Mich., July 6, 1914:

Data.	Lakes.			
	Superior.	Michigan and Huron.	Erie.	Ontario.
Mean level during June, 1914:	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Above mean sea level at New York	602.49	580.60	573.04	246.91
Above or below—				
Mean stage of May, 1914	+ 0.16	+ 0.28	+ 0.13	− 0.04
Mean stage of June, 1913	+ 0.13	− 0.60	− 0.82	− 1.11
Average stage for June, last 10 years	+ 0.19	− 0.47	+ 0.02	− 0.23
Highest recorded June stage	− 0.94	− 3.00	− 1.48	− 1.72
Lowest recorded June stage	+ 1.25	+ 0.70	− 1.47	+ 2.02
Probable change during July, 1914	+ 0.2	+ 0.10	− 0.1	− 0.1

FLOOD STUDIES AT LOS ANGELES.[1]

By FORD A. CARPENTER, Local Forecaster.

[Dated, Weather Bureau, Los Angeles, Cal., Apr. 8, 1914.]

[An address before the southern California association of members of the American Society of Civil Engineers, Los Angeles, Cal., Apr. 8, 1914.]

Introduction.

The rainstorm of February 18–21, 1914, caused the most damaging but not the greatest flood in the history of Los Angeles. Railway and street traffic were interrupted for a period exceeding 24 hours, bridges and roadbeds were destroyed, the harbor was silted, and some ranches and orchards swept bare. The property loss probably exceeded $3,000,000. This was offset many times over by the great amount of good this storm did in filling the depleted mountain reservoirs, raising the level of the valley ground water, and amply soaking the hundreds of thousands of acres of agricultural land in the Los Angeles district.

If such floods were matters of rare occurrence, and the resulting damage could not be prevented, then the monetary loss and the temporary inconvenience might be forgotten, or the "unusual" weather remembered as being among the rare occasions in southern California when meteorological conditions were not favorable. But such is not the case, as will be shown by the accompanying tables and charts recording weather conditions since the establishment of the local Weather Bureau station 37 years ago. The object of this present paper is to give some of the contributing causes of these floods in general, and of the last February storm in particular. It is also desired to set forth a brief history of past floods in Los Angeles and detail some of their pertinent features.

As is well known, there is but one reason for the production of rain, viz, condensation of atmospheric moisture far below the saturation point. In southern California this condensation is brought about primarily by the action of the eddying winds in a storm center and the attendant upward deflection of moisture-bearing winds. Owing to the general eastward drift of the earth's atmosphere in these latitudes, the air from the Pacific Ocean reaches us moist and of nearly constant temperature. Precipitation occurs in southern California whenever there is sufficient atmospheric disturbance to expand and cool the moisture-laden winds far below their dew point. This disturbing feature is almost invariably an aerial eddy, the familiar "low" of the weather map. Whenever the path of a low-pressure area extends as far south as latitude 40° N., precipitation results in this portion of the State. The amount of the precipitation is determined generally by the blocking of a ridge of high pressure, which prevents the normal eastward drift of the storm area. It is thus seen that southern California would be practically rainless all of the time instead of more than half the year, were it not for the slight southward deflections of the paths of the northern storms.

An examination of a chart of annual rainfall shows remarkable variations in the amount and distribution of the seasonal fall. The rainfall in southern California is evidently one of the least dependable of meteorological elements. The irregularity of the seasonal rainfall is further shown by the wide difference between the normal annual rainfall of 15.5 inches at Los Angeles and the extremes of 5.6 inches (1898–99) and 38.2 inches (1883–84). As it is, rain occurs only during a fraction of the year. Los Angeles has an average of but 16 days with a quarter of an inch or more of rain and only 5 days with an inch or more.

Monthly distribution of precipitation.

In figure 1 the rainfall for each month is plotted around a center representing zero and circles are drawn for each inch of rainfall. The radials are the months of the year.

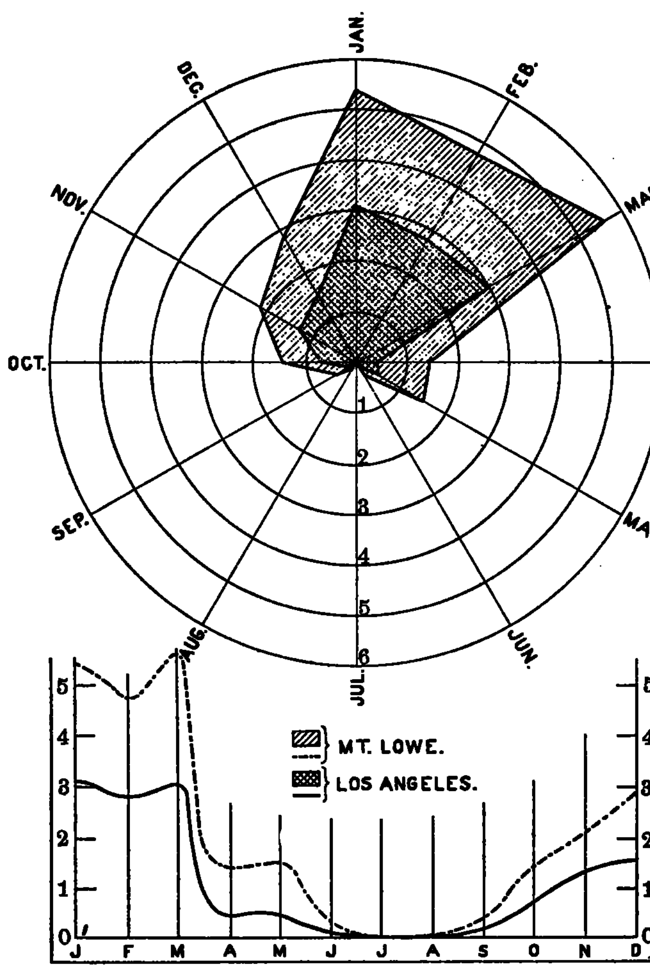

Table of average precipitation at Los Angeles (412 feet) and Mount Lowe, Cal. (3,420 feet), for the 17 complete years 1896–1902, inclusive, and 1904–1913, inclusive (inches).

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
Mount Lowe	5.43	4.78	5.66	1.41	1.46	0.31	0.01	0.09	0.39	1.43	2.14	2.87	25.98
Los Angeles	3.08	2.82	3.03	0.42	0.47	0.08	0.01	0.02	0.17	0.71	1.27	1.52	13.60

FIG. 1.—Diagrams and table of annual march of average precipitation at Mount Lowe (3,420 ft.) and Los Angeles, Cal. (alt. 412 ft., A. S. L., 151 ft. above ground.)

[1] The author desires to acknowledge courteous assistance rendered by the local officers of the U. S. Corps of Engineers, the U. S. Forest Service, the manager California Fruit Exchange, and many individuals who contributed precipitation data.

FIG. 2.—Mount Lowe, Cal., during the rain of February 20, 1914.

It is the rose of annual rainfall constructed for two homogeneous sets of 17 years. This rose has the advantage of showing continuity in the distribution of rainfall, and is more graphic than the ordinary block system, no matter whether this latter arrangement begins with January or July. This diagram and its accompanying table illustrate two important climatic features—first, the average annual distribution of rainfall, and second, the relationship between rainfall and elevation. Two stations are shown, Los Angeles and Mount Lowe. Mount Lowe was selected because of its proximity to Los Angeles, being within 15 miles of the city and a trifle over 3,000 feet higher. Of course the data cover the same years at both stations. It will be seen from the rain-rose that practically all the precipitation occurs within the months of December, January, February, and March.

Relationship between elevation and precipitation.

A cursory glance at the chart shows a remarkable similarity in the annual distribution as well as in the relative monthly amounts at each station. The rainfall at the Observatory exceeds that in the city by over 60 per cent, although the seasonal distribution is nearly uniform. Locally, precipitation is increased at a somewhat regular rate whenever a mountain range near the coast faces the rain-bearing winds. The upward deflection of the moist wind brings about precipitation commensurate [within limits] with the elevation. The reason for this is that the air is slanted upward and is cooled by expansion at the rate of 1° F. for about every 180 feet of ascent. Thus, in the case of Mount Lowe, a cubic foot of air making the ascent of 3,000 feet would cool 16° if it neither gained heat from nor lost heat to its surroundings. A telephotograph of the clouds due to this cooling process is shown as figure 2. It is hardly necessary to state that it is not the actual contact of the moist wind with the mountain slopes or hillsides that produces cloudy condensation in the atmosphere, although condensation does frequently occur upon rocky headlands or ice-covered surfaces.

The convectional action of thunderstorms may be entirely disregarded as a rain producer in the Los Angeles region, as it will be noted that less than one-tenth of an inch of rain falls during the summer months.

It will be seen by the accompanying chart, figure 3, that for convenience of study the Los Angeles drainage district has been made to embrace a region about 70 miles long by 60 miles wide. This includes Los Angeles, Orange County, and portions of Riverside and San Bernardino Counties. In this territory there are three rivers, the Los Angeles, the San Gabriel, and the Santa Ana. During most of the year water is flowing in different portions of these streams. The rivers appear and disappear as their courses cross sand, silt, loam, or rock. Not always do these streams reach the sea. They have their rise in the northern and northeastern mountains of the Los Angeles district and their valley bed is of easily disintegrating soil, such as decomposed granite and loam along the foothills and silt and adobe in the other sections.

Distribution of precipitation during a typical heavy flood.—The records of precipitation (rain and melted snow) during the storm of February 18–21, 1914, from 42 stations have been collected and tabulated in Table 1. In order to present a picture of the distribution of the precipitation, lines representing areas of from 3 to 19 inches of rainfall have been drawn. The resulting precipitation map (fig. 3) shows that the valleys received on an average of less than 7 inches during these three days, while the moderate elevations of 2,000 feet, with a southwestern exposure, received from 12 to 14 inches. The highest districts received approximately 20 inches.

TABLE 1.—*Total precipitation, February, 1914, in the Los Angeles district. All fell on the 18th, 19th, 20th, and 21st.*

Stations.	Rainfall.	Stations.	Rainfall.
	Inches.		*Inches.*
Avalon	3.45	Palos Verde	3.87
Azusa	13.26	Pasadena	11.44
Bear Valley Dam	10.83	Pomona	9.60
Chino	4.81	Redlands	4.26
Claremont	10.92	Redondo	3.51
Cleghorn Canyon	17.85	Riverside	2.79
Corona	4.31	San Antonio Canyon	12.25
Devil Canyon	8.63	San Bernardino	4.71
East Highlands	4.85	San Dimas	11.29
Fillmore	6.44	San Fernando	8.88
Garvanza	9.41	San Pedro	2.03
Highland	5.68	Santa Monica	5.50
Hollywood	6.75	Sierra Madre	15.56
Long Beach	3.24	Squirrel Inn	16.29
Los Angeles	7.07	Tustin	3.52
Mill Creek	11.10	Valyermo, post office	5.57
Mount Lowe	19.20	Venice	5.16
Mount Wilson	19.40	Ventura	10.21
Orange	3.55	Walnut	6:96
Palm Springs	3.90	Whittier	5.02

The progress of the storm of February 18, 1914.—The Weather Map of the Northern Hemisphere for February 18, 1914, showed an unusually large area of low pressure, extending from eastern Asia to southern California. It was the southern portion of this low area which made its appearance first over the Washington coast. On the 19th and 20th the storm had extended southeastward, although still off the Pacific coast. On the 21st the storm area showed indications of dividing. This separation took place the next day and the storm was central over the western portion of the United States. On the 23d the storm, much reduced in size, occupied the Gulf States. On the 24th it moved along the south Atlantic coast and by the 25th it was off Newfoundland, where it remained stationary. On the 27th it recurved, but by the 28th it was well at sea headed for Iceland, where it was located the next day. This storm, as traced in figure 4, thus traveled halfway around the world from its birth in the Aleutian Islands on February 18 to where it passed beyond the limits of observation on March 1.

History of past floods.

For the past 37 years the local office of the United States Weather Bureau has maintained a fairly detailed account of the occurrence of all floods in the vicinity of Los Angeles. The record is shown in Table 2. Los Angeles has experienced 15 light floods, 18 moderate floods, and 8 heavy floods, and only during 9 of the 37 years has this vicinity been free from these occurrences. The most serious flood in the history of this region was that of 1884; and the largest number of floods in any one year came in 1889, when one occurred in March, another as early as October, and three more in the following December. The records of the United States Engineers show that the Los Angeles Harbor at San Pedro has been silted five times, viz, 1884, 1889, 1890, 1911, and 1914.

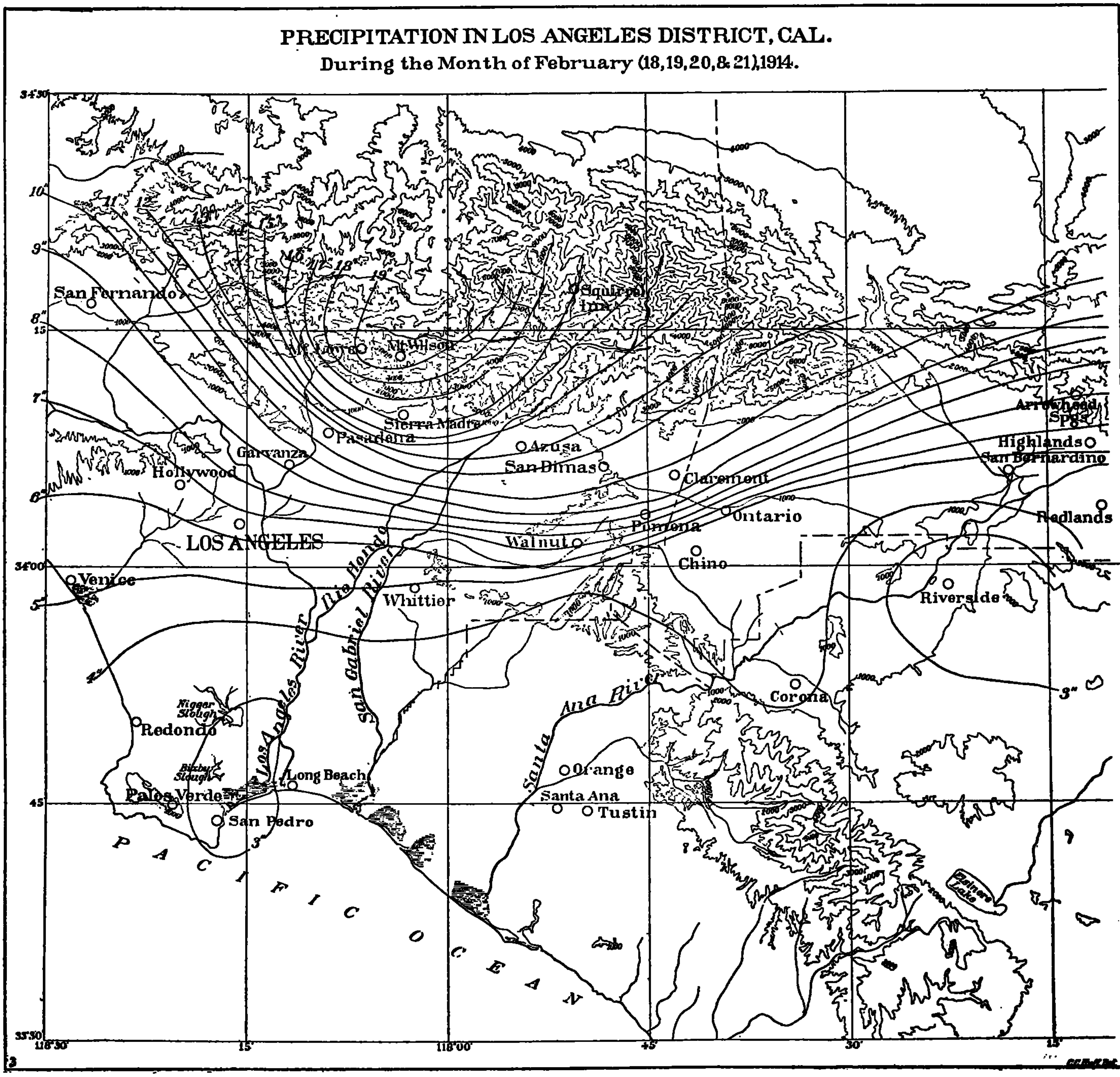

Fig. 3.—Isohyetal map of the Los Angeles district for February 18–21, 1914.

TABLE 2.—*Floods in vicinity of Los Angeles, Cal., for the 37 years 1878–1914.*

No.	Dates.	Precipitation, 24 hours.	Flood character.	Remarks.
		Inches.		
1	1878, Jan. 16	1.16	Light	Bridges washed away.
2	Feb. 19	1.33	Moderate	Do.
3	1879, Dec. 20	4.34	...do	Mountain streams swollen. Bridges washed away. Railway travel suspended.
4	1880, Dec. 20	2.26	...do	Streets almost impassable.
5	1884, Feb. 17	3.56	Heavy	Severe flood. Great amount of damage. (Harbor silted.)
6	Mar. 9	2.67	...do	Los Angeles River in flood. Houses washed away.
7	1886, Jan. 19	3.77	...do	Lower portion of city under water. Flood quite severe. Several lives lost.
8	1887, Feb. 16	3.94	Moderate	Severe flood, but not so bad as last year. Lower part of city flooded.
9	1888, Jan. 4	3.39	...do	Several washouts in vicinity.
10	Dec. 23	2.72	...do	Many washouts. Streets flooded. Damage not commensurate with severity of storm.
11	1889, Mar. 17	2.53	Light	Washouts. Streets in bad condition. River did not overflow.
12	Oct. 23	3.62	Moderate	Washouts on railroads. Unprecedented rainfall for this time of year. Streets flooded.
13	Dec. 12, 15	4.30	Heavy	Traffic paralyzed by washouts. Streets flooded.
14	Dec. 25	3.82	...do	The flood was scarcely less severe and disastrous than that of 1884. (Harbor silted.)
15	1890, Jan. 26	4.17	...do	Flood. Streets turned into rivers. Traffic suspended. (Harbor silted.)
16	1891, Feb. 23	2.75	Moderate	Many washouts. Bridges carried away. River high.
17	1893, Mar. 21	2.82	...do	Streets flooded.
18	1894, Dec. 21	1.33	Light	Do.
19	1895, Jan. 17–18	1.73	...do	Do.
20	1896, Dec. 28	1.22	...do	Do.
21	1897, Jan. 14–15	1.57	...do	Do.
22	Feb. 20	2.02	...do	Do.
23	1900, Nov. 21	3.79	Moderate	Flood.
24	1901, Feb. 6	2.55	Light	Streets flooded.
25	Oct. 27	1.79	...do	Streets flooded. Railroad traffic temporarily suspended.
26	1902, Nov. 11	1.95	...do	Streets flooded.
27	1903, Mar. 25	3.35	Moderate	Do.
28	1905, Feb. 4	2.25	Light	Do.
29	Mar. 13	2.41	Moderate	San Gabriel and Santa Ana Rivers very high. Streets flooded. Traffic interrupted.
30	1906, Jan. 19	2.20	Light	Streets flooded, but no serious damage.
31	Mar. 26	1.75	Moderate	Los Angeles River higher than for many years. Streets inundated.
32	1907, Jan. 7–8	1.64	Light	Streets flooded.
33	1908, Jan. 24	1.76	...do	Do.
34	1909, Jan. 21–22	3.17	Moderate	Streets flooded. Traffic interrupted.
35	Dec. 31	1.99	...do	Streets flooded.
36	1911, Jan. 28	2.97	...do	Do.
37	Mar. 9	1.99	Heavy	Streets flooded. Traffic interrupted. (Harbor silted.)
38	1912, Mar. 9–12	2.04	Light	Streets flooded.
39	1913, Feb. 24	5.12	Moderate	Streets flooded. Traffic interrupted.
40	1914, Jan. 25	2.60	...do	Do.
41	Feb. 18	4.26	Heavy	Streets flooded. Traffic interrupted. Bridges washed away. (Harbor silted.)

Contributing causes shown by accumulated rainfall profiles.—Figure 5 (p. 390) is a profile of accumulated daily rainfall in which the record is made to begin October 2 and end with April 2. The horizontal values are in inches and hundredths and the vertical divisions in days and decades. A glance at this chart will show that in a majority of seasons the floods occur after the second heavy rain, provided the interval between the storms is not too long. If the rain is steady, allowing the water to soak into the thirsty soil, floods will not occur, no matter how great the total rainfall. For example, on December 31, 1878, no flood occurred although 3.58 inches fell in the 24 hours; as also in 1892, when 3.75 inches were precipitated on November 29; and again on February 1, 1897, when 2.13 inches were recorded. But without an exception, in these instances floods occurred during the next period of rainy weather. The profiles do not reveal any instance where floods occurred simultaneously with the first storm. They indicate that there are three important factors in the production of floods in the Los Angeles district: First, the interval elapsing between the last rain and the flood; second, the rapidity of the rainfall, and third, the total amount deposited.

During the past 15 years the local office of the Weather Bureau has maintained automatic rain gages which give very satisfactory records of the actual rate of fall in 1-minute and 5-minute periods. This record is shown in Table 3. It may be summarized as follows: The greatest amount in any 5-minute period was 0.36 inch, between 1 p. m. and 1:30 p. m., February 18, 1914; and during the same hour the 10-minute record of 0.66 inch was established, as was also the 15-minute record of 0.81 inch, and the greatest amount in 30 minutes, 1.12 inches. The greatest amount in one hour, 1.51 inches, fell on February 18, 1914; of this amount 1.16 inches occurred in 32 minutes. The rate of 2.50 inches in 24 hours was maintained for 20 hours and 27 minutes during this storm. The greatest amount in 24 hours was 5.12 inches, which fell on February 23–24, 1913. Excessive rainfall, as automatically registered on the day of the 1914 storm, is shown in detail by Table 4 and graphically by figure 6 (p. 391).

TABLE 3.—*Excessive precipitation at Los Angeles, Cal., for the 15 years, 1899–1914.*

Duration.	Amounts.	Dates.	Pacific time.
	Inches.		
5 min	0.12	Jan. 2, 1899	7:38 p. m. to 7:43 p. m.
Do	.20	Feb. 2, 1905	(Early morning.)
Do	.15	Feb. 10, 1906	
Do	.22	Mar. 12, 1906	
Do	.18	Mar. 5, 1907	
Do	.14	Jan. 21, 1909	Between 3 and 4 p. m.
Do	.15	Mar. 4, 1912	10:08 a. m. to 10:13 a. m.
Do	.11	Mar. 6, 1912	6:28 a. m. to 6:33 a. m.
Do	.14	Mar. 12, 1912	11:44 a. m. to 11:49 a. m.
Do	.14	Jan. 15, 1913	
Do	.24	Nov. 12, 1913	
Do	.28	Jan. 18, 1914	Between 5 a. m. and 6 a. m.
Do	.36	Feb. 18, 1914	Between 1 p. m. and 1:30 p. m.
7 min	0.51	Jan. 14, 1908	4:16 a. m. to 4:23 a. m.
Do	.23	Feb. 9, 1908	6:38 a. m. to 6:45 a. m.
10 min	0.40	Nov. 12, 1913	
Do	.42	Jan. 18, 1914	
Do	.66	Feb. 18, 1914	
15 min	0.44	Nov. 27, 1905	
Do	.48	Jan. 18, 1914	
Do	.49	Nov. 12, 1913	
Do	.81	Feb. 18, 1914	
20 min	0.75	Nov. 17, 1900	Between 12:30 p. m. and 1 p. m.
30 min	0.68	Mar. 13, 1905 Nov. 12, 1913	
Do	1.12	Feb. 18, 1914	
60 min	1.51	Feb. 18, 1914	
24 hours	5.12	Feb. 23, 1913 Feb. 24, 1913	
Do	4.26	Feb. 18, 1914	

Lessons from the flood.

Loss by heavy rain is not unknown in the Los Angeles district, the flood of 1914 being the third severe flood in local history, and the eighth known heavy flood. Records show that the floods of 1884 and 1889 were more serious than that of 1914. In fact, there appears to be no question but that another series of heavy rains which characterized the floods in the spring of 1884 would make the last storm appear inconsequential. It should be remembered that when the great flood took place 30 years ago, Los Angeles was a town of probably less than 20,000 inhabitants. With its present population of approximately half a million, the run-off area has been greatly increased owing to the thousands of acres of roofs, paved streets, sidewalks, etc., while the absorption area has been correspondingly lessened from the same cause. The steady progress in building, especially during the last decade, has indirectly diminished the damage by floods because of the resultant considerable consumption of sand in the manufacture of concrete. This sand, dredged from the Los Angeles River, has proportionately deepened the channel of the river where it passes through the city.

It has been estimated that New York City's last snowstorm cost $2,500,000 for snow removal alone, and that the storms resulted in damage amounting to $5,000,000 at the lowest conservative estimate.[2] While the damage by one of the comparatively infrequent floods in Los Angeles does not much exceed the cost of removing snow from the streets of New York City during an ordinary snowstorm, and there can be no question but that the growth of the city and attendant rapidly increasing value of city and surrounding property will make the drainage and utilization of storm waters the most important questions now before the people of this city and surrounding region.

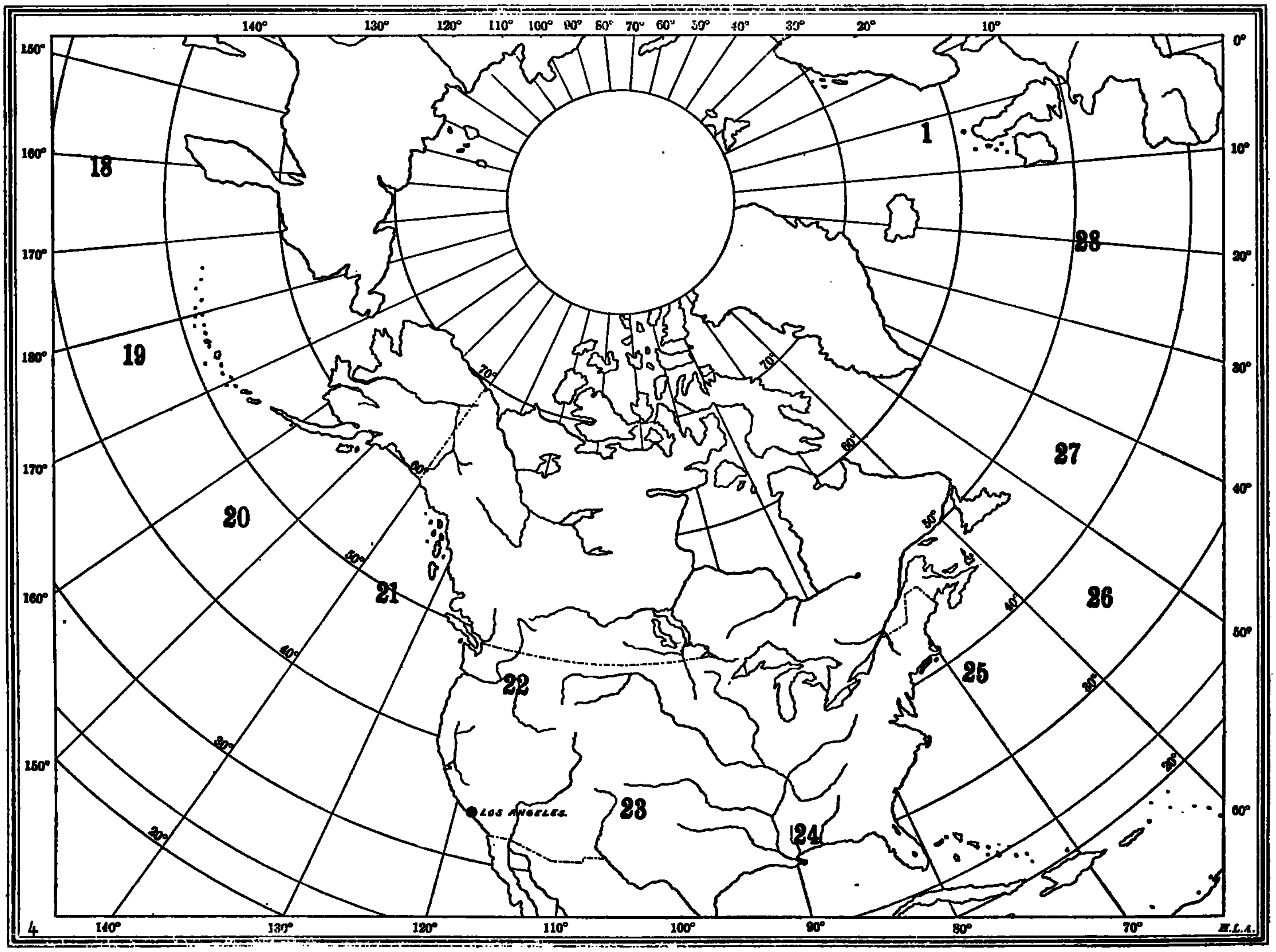

Fig. 4.—Progress of the storm of February 18, 1914. The dates Feb. 18–Mar. 1 indicate successive positions of the center.

Table 4.—*Excessive rainfall automatically registered Feb. 18, 1914, at the local office, United States Weather Bureau, Los Angeles, Cal.*

[1.16 inches in 32 minutes.]

ACCUMULATED DEPTHS, CONSECUTIVE PERIODS, MINUTES.

[Excessive rate began 12:27 p. m., ended 1:56 p. m., local time (Pacif. stand. T.).]

	Inches.
5 minutes	0.06
10 minutes	.11
15 minutes	.21
20 minutes	.29
25 minutes	.32
30 minutes	.35
35 minutes	.41
40 minutes	.45
45 minutes	.55
50 minutes	.63
60 minutes	.86
80 minutes	1.73
100 minutes	1.90

[2] Eng'r'g record, Mar. 28, 1914, No. 13, 69:354.